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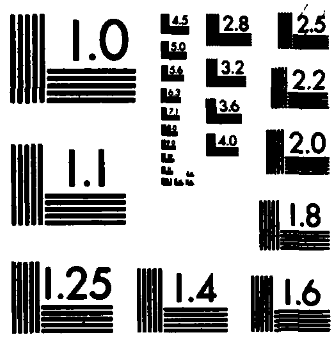

MICROCOPY RESOLUTION TEST CHART
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18. SUPPLEMENTARY NOTES

Previous open literature publication - Igor Alexeff and Fred Dyer, Phys. Rev. Letters 45, 351 (1980).

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Millimeter Microwave Emission, Microwave Maser, Electrostatic Free-Electron Maser, PLasma Oscillations.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Five major advances in the study of the orbitron electrostatic maser have been made during the past 12 month period. These can be tabulated as follows:

1. Reliable pulsed operation at the short wavelength of 2 millimeters;
2. Demonstration of narrow-band pulsed emission at the longer

wavelength of about 1 centimeter;

3. Demonstration of continuous emission in a narrow band at the still longer wavelength of about 30 centimeter;

4. Identification of a second mode of maser operation in which the electrons move radially rather than azimuthally;

5. Success in a computer description of 3-dimensional electron orbits in the electrostatic potential wells.

In addiiton to the five major milestones described above, considerable progress has been made in the experimental, theoretical, and computational study of the device.

b. Research Objectives

The object of this research is to develop a practical submillimeter microwave oscillator and amplifier in the wavelength range 4 mm - 0.1 millimeter. The mechanism for microwave production is by stimulated microwave emission from electrons orbiting a positively-charged wire. The advantage of this process over stimulated emission from electrons orbiting in a magnetic field is that in general much shorter wavelengths can be produced, and bulky magnets are not needed.

The basic process is that electrons produced near the wall of a cavity resonator are attracted to a positive wire near the center. If the electrons possess a small amount of initial kinetic energy, they generally have angular momentum relative to the wire, cannot reach the wire, and go into orbit around it. The electrons are prevented from escaping by drifting parallel to the wire by means of appropriately charged electrodes, such as negative end walls.

The resulting trapped cloud of electrons orbiting the wire is unstable, and if a microwave signal of the appropriate frequency is present in the cavity, it will grow. The electron cloud loses energy to the microwave signal, collapses on the wire, and is lost. By appropriate electron feed to maintain the supply of electrons, the microwave emission may be made steady-state.

This microwave production process is directly analogous to that in a conventional microwave maser, except that the electrons orbiting the positively-charged wire replace the electrons orbiting positively charged atomic nuclei. The advantage of this new maser over conventional masers is that by adjusting the diameter and the potential of the positive wire, the emission frequency may be adjusted to a desired value. In addition, for reasonable wire diameters and potential values, the frequencies lie in the desired millimeter and sub-millimeter wavelength ranges.

Previous experiments have demonstrated pulsed microwave emission at several watts in the wavelength range 3 cm to 4 mm. In this report, we relate the progress we have made in the past year in the study of this maser.

c. Status

TEXT

A detailed description of the our progress is tabulated below.

1. Reliable 2 mm operation

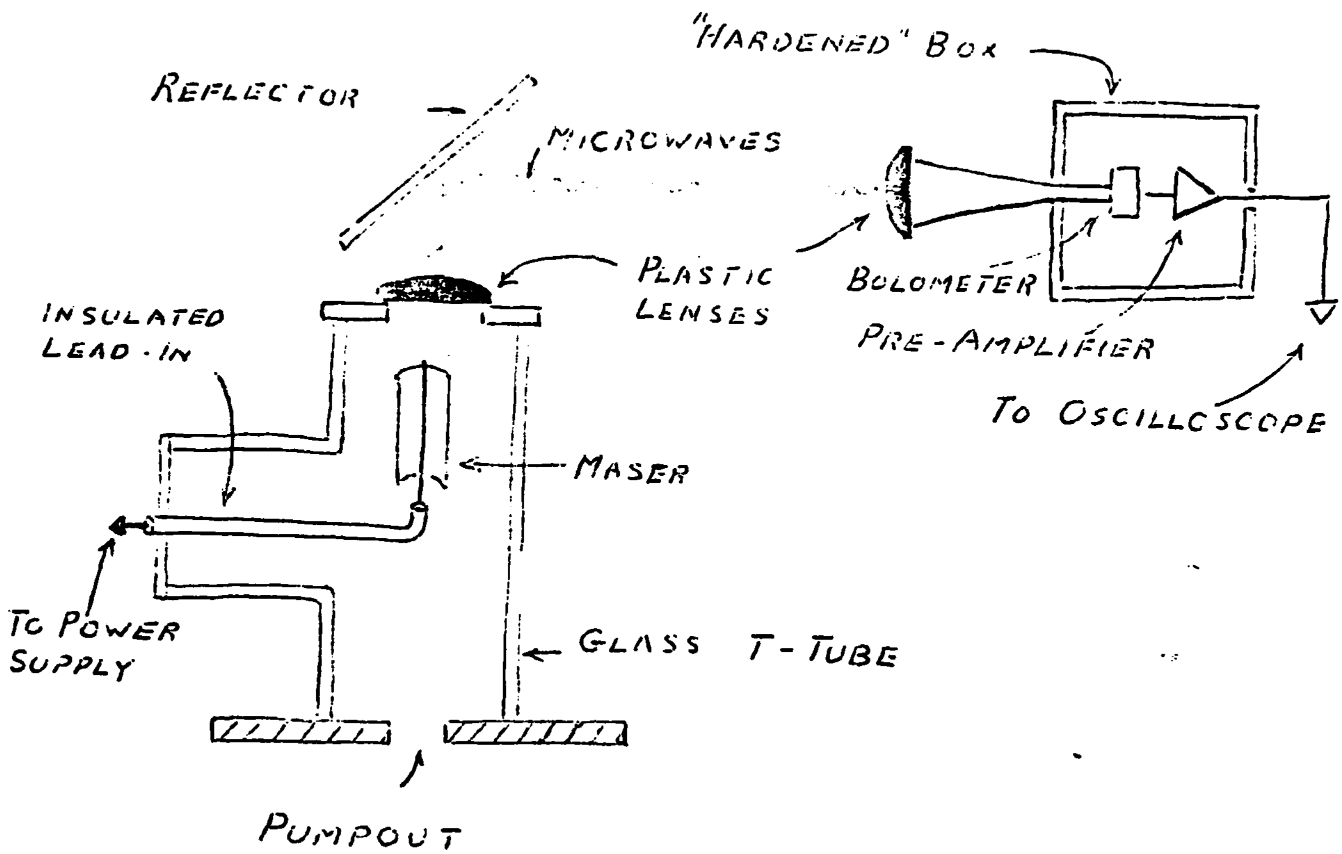
We found that part of our problem in operating at 2 mm was that microwave radiation at this wavelength is absorbed strongly by glass. Consequently, we first used a plastic (TPX) window on our demountable microwave system. This apparatus is shown in FIG. 1. We then manufactured a small, portable tube in which the main body of the tube is fused quartz. As both the wire lead-ins and the vacuum seal-off valve are made of ordinary pyrex glass, the transitions from pyrex glass to fused quartz are made via graded seals.

A second part of our problem in operating at 2 mm is that our present microwave detectors are rather insensitive. Consequently, the high-voltage transient from our pulsed power supply would leak into our oscilloscope system and override the microwave signal. This problem was solved by placing the microwave detector along with a battery - operated preamplifier inside a specially - designed, radiation - hardened box. This screening essentially eliminated all pick-up. Our detectors at = 2 mm are as follows:

1. A hot-wire bolometer from TRG.
2. A 4 mm TRG microwave diode used with residual sensitivity at 2 mm.
3. A Hughes 2 mm diode. This last is very sensitive, but prone to burn-out. We have rebuilt ours 3 times.

Once the pick-up problems were eliminated, we could explore the properties of the microwaves with ease. We used wire meshes of different sizes as high-pass filters (in transmission) and as low-pass filters (in reflection). Microwave absorbtion and interference experiments were readily done.

2. Demonstration of narrow-band emission near $\lambda = 1$ cm.



SCHEMATIC OF 2-MILLIMETER MASER SYSTEM

Figure 1

This demonstration of narrow-band emission was made possible by our obtaining a high-frequency, panoramic receiver from INTEGRA by means of our AFOSR grant. This panoramic receiver is unique in that it is not a superheterodyne receiver, and so does not suffer from improper frequency identification via images. It covers the relatively broad range of 1 to 28 GH_z.

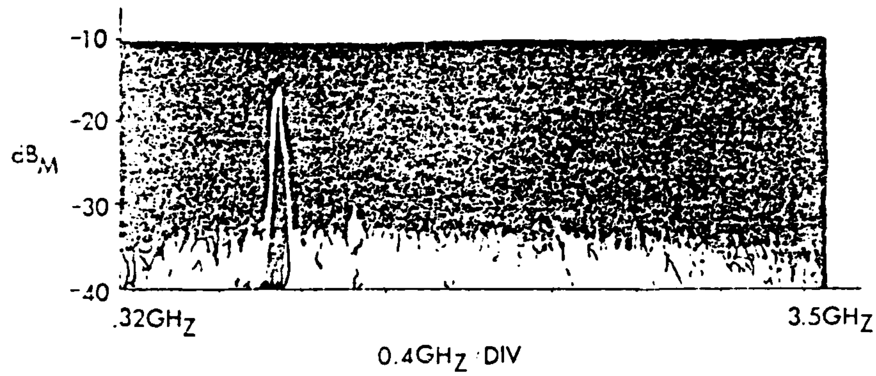
Unfortunately, in our pulsed mode of maser operation, the microwave emission signal on the panoramic receiver is obscured by the light from the steady-state trace. The microwave signal can be seen, but is difficult to photograph. We solved this problem by transferring the signal from the panoramic receiver to an oscilloscope, and by applying appropriate Z-axis modulation to the oscilloscope so that the trace only appeared when microwave emission was present. With this Z - axis modulation, the microwave spectrum was photographed easily. The spectrum was found to be narrow, $\Delta\lambda\, 2/2\, \lambda \approx 0.01$. This supports our model of coherent maser action. A noise source would be broad-band.

3. C. W. operation.

Our new panoramic receiver allows us to operate at lower frequencies than before. Our early microwave apparatus was limited to 3 cm, but the panoramic receiver goes down to 30 cm. At this lower frequency, the orbiting electrons require less voltage. Therefore, less power is required for maser action and we can obtain continuous operation at 400 volts and 1/2 ampere (see FIG. 2). Presumeably, higher frequency C. W. operation will be readily obtained when higher - power D.C. supplies are obtained. Experimentally, at all frequencies, we find that the maser threshold is at about 1/2 to 1 ampere.

4. Identification of a second mode of maser operation in which the electrons move radially rather than azimurthally.

Using our new panoramic receiver obtained with our AFOSR grant, we observed



Plasmon Emission from Orbitron at 1.18GH$_Z$.

Figure 2

lines of emission from our portable tube that were too low to correspond to cavity modes. The frequencies did correspond to those predicted if the cylindrical cavity resonator corresponded to the outer conductor of a co-axial line, and the inner wire, to the center conductor.

For this kind of mode to be excited, electron motion in the radial direction, rather than in the azimuthal direction had to be unstable. We verified that this was indeed the case, and that this instability had the characteristics of a negative-mass instability. The remarkable result is that radial oscillations have frequencies not far (30% away from) azimuthal oscillations.

We note that this continuous-wave emission also appears in narrow, well defined bands as would be expected from coherent maser operation. The exact prediction of the observed frequency-about one GH_Z- is not possible due to the complex structure of the cavity resonater at this frequency. We believe that this mode is due to radial electron oscillations and that the cavity resonator includes the central positive wire in its radiation structure. Thus, it acts as a re-entrant cavity resonator. Our approximate estimation of the observed frequency fits the frequency to about 30% - See below.

5. Success in Computer Code.

We have developed a 3-dimensional computer code that follows the motion of an electron around a positively-charged wire with negative end plates. The code also follows an electron around a positively-charged wire containing etched steps. In this latter case, the steps on the wire form local electrostatic mirrors, smaller orbits can be confined, and higher frequencies are attained. The etched wire is the main reason for successful operation at $\lambda = 2$ mm.

Our code is successful in that as the electrons orbit the wire in precessing ellipses and bounce from the electrostatic mirrors, we find that the total energy of the particle is well-conserved. We observe that energy can be transferred from the axial to the radial direction. However, particles in general cannot escape from the system (see FIG. 3).

We have also proved analytically that there is a class of particles that cannot excape from the system. These particles need to possess sufficient angular momentum around the wire-a quantity that is conserved in a cylindrically-symmetric potential well.

In addition to the above five major milestones, we continue to progress in our understanding of the microwave emission process and in our ability to study the emission process. We have ordered or are obtaining quotations for microwave apparatus that should be useful below $\lambda = 1$ millimeter.

Our experiments are arousing interest elsewhere. We were invited to give a 30 minute invited paper at the Plasma Physics Divisional Meeting in New York in 1981. Hughes Research Labs in Malibu had me over for a presentation, then sent an engineer to work in our laboratory for a day. We sent them two 2-mm tubes, and they report to us that emission is observed. I was invited to the partly-classified microwave tube conference at the Naval Postgraduate School in Monterey. A colloquium was given at the Naval Research Laboratory in Washington, D.C. We have been approached for possible future projects by ARO and DOE. Thus, the project seems important because it does arouse outside interest.

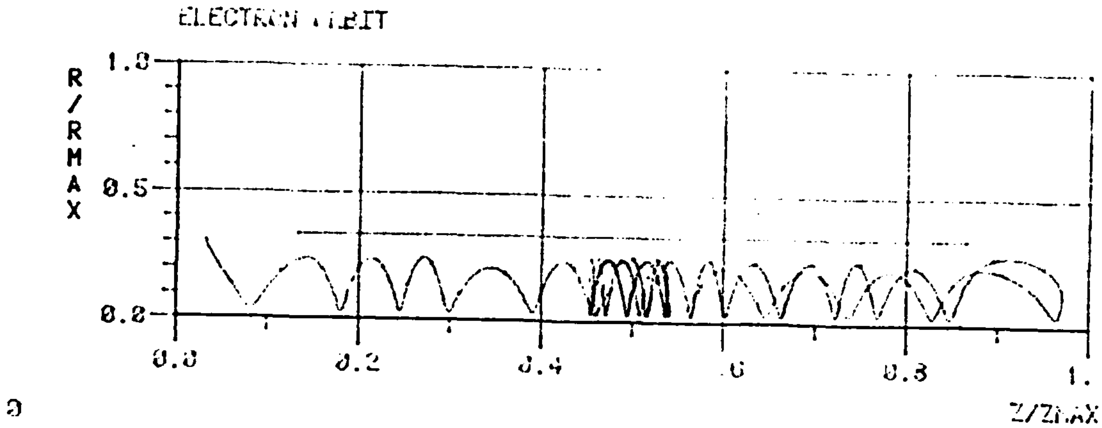


Figure 3 (a)

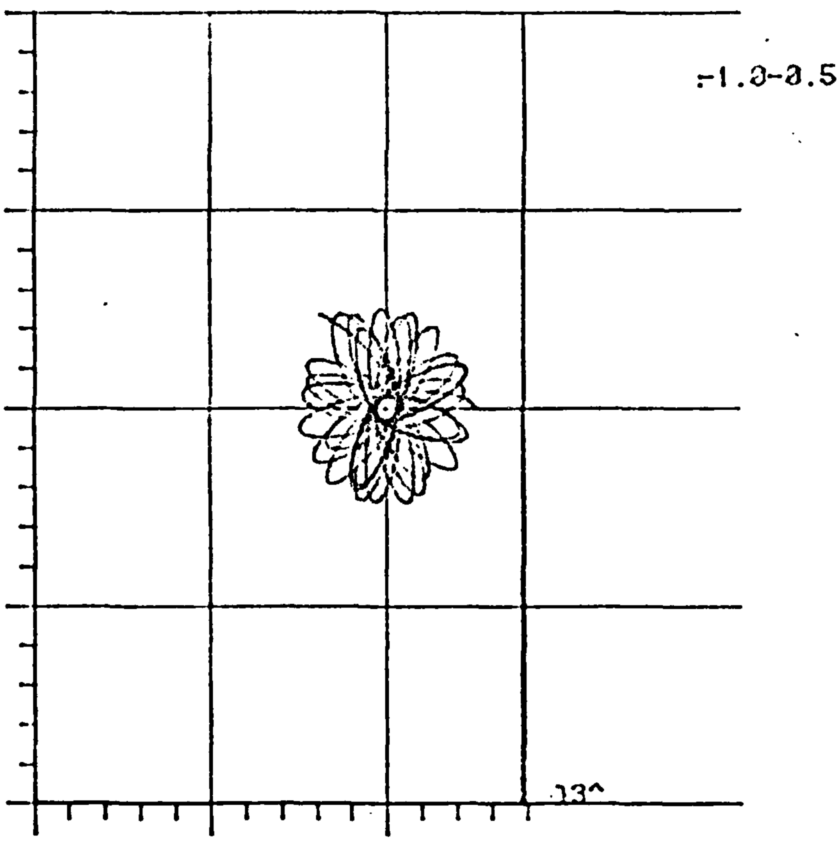


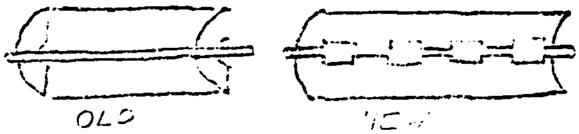
Figure 3 (b)

Abstract Submitted
For the Twenty-third Annual Meeting
Division of Plasma Physics
October 12 to 16, 1981

Category Number and Subject 4.8 Microwave Generation

☐ Theory ☒ Experiment

Advances in Millimeter Microwave Emission from a Maser using Synthetic Atoms; Igor Alexeff and Fred Dyer, U of Tn.*----We have eliminated phase mixing and Z-axis Landau damping losses in our orbitron maser. In the past(1) we have demonstrated millimeter microwave emission from electrons orbiting a positively-charged wire placed inside a cavity resonator. By placing multiple notches on the wire, we produce a series of electrostatic mirrors that confine electrons locally, rather than allowing them to drift back and forth parallel to the wire (Z-axis).



We have also developed a plasma analog of the Schottky diode and have successfully detected a few milliwatts of radiation at 3cm.

*Supported in Part by USNSF Grant ENG-78-03400

[1]Igor Alexeff and Fred Dyer, Phys. Rev. Letters 45,351 (1980).

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Submitted by:

(signature of APS member)

Igor Alexeff
(same name typewritten)

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(address)

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Division of Plasma Physics Annual Meeting
c/o Ms. Joan M. Lavis
Grumman Aerospace Corporation
105 College Road East
Princeton, New Jersey 08540

Abstract for an Invited Paper

for the Division of Plasma Physics

Twenty-Third Annual Meeting,

American Physical Society, New York, N. Y.

12-16 October

Millimeter Microwave Production from a Maser by use of Electrons Orbiting a Positively-Charged Wire (Synthetic Atoms)*. Igor Alexeff, University of Tennessee, Knoxville. (30 min.)

Plasma-Produced electrons have been trapped electrostatically for long periods of time in orbit around a positively-charged wire. Since the frequency of rotation of each electron increases i it loses kinetic energy and sinks into the positive-potential well, phase bunching resulting in intense microwave emission has been easily excited. The basic advantage of this electrostatic microwave emitter over a magnetically confined electron device is that, theoretically, by use of readily available voltages and wire sizes, it can operate at free-space wavelengths down to at least 0.1 mm. In addition, since the orbit frequency is a function of electron energy, relativistic electrons are not required for operation. Examples of spontaneous emission at 3 cm to 4 mm will be shown, as well as q-spoiled operation, and stimulated emission. So far, pulsed emission has been produced with a peak value of 10 watts at 3 cm > λ > 4 mm for about 10μ sec An externally imposed magnetic field turns off the emission process. The evolution of several devices from the "beer-can-cavity" original[1] to the latest "open-cavity" design will be discussed.

* ,pported in part by U.S. National Science Foundation Grant No. ENG-78-03400.

1. Igor Alexeff and Fred Dyer, Physical Review Letters 45, 351 (1980).

Abstract Submitted
For the Twenty-fourth Annual Meeting
Division of Plasma Physics
November 1 to 5, 1982

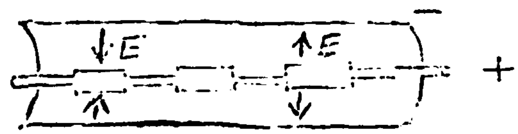
Category Number and Subject

☐ Theory ☒ Experiment 4.8 microwave generation

Microwave Emission Characteristics of the Orbitron Electrostatic Free-Electron Maser*, IGOR ALEXEFF, FRED DYER, HAMID F. KARIMY and WLODEK NAKONIECZNY University of Tennessee, Electrical Engineering Dept.-- We have measured both the line width and the peak power of the lowest-frequency mode of our latest electrostatic free-electron maser[1]. The full-width frequency spread at half peak power was measured to be less than 10% of the frequency. The peak power emitted was 100 milliwatts, 60 db above above noise background. The fundamental mode appeared at 1.7 Ghz, and corresponds to the central wire and surrounding cylindrical cavity forming a resonant section of coaxial line. Such a mode couples well to the highly elliptic electron orbits which computer simulation predicts for the electrons initially.

*Supported by the Air Force Office of Scientific Research under contract AF AFOSR-82'-0045 Alexeff

[1]Igor Alexeff and Fred Dyer, Phys. Rev. Letters 43,351 (1930).



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University of Tennessee, Knoxville
(address)

This form, or a reasonable facsimile, plus *Two Xerox Copies* must be received NO LATER THAN NOON, July 30, 1982, at the following address:

Ms. Barbara Safarty
Princeton Plasma Physics Laboratory
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Princeton, New Jersey 08544

ABSTRACT SUBMITTED FOR THE

1982 IEEE INTERNATIONAL CONFERENCE ON PLASMA SCIENCE

MAY 17-19, 1982

Extended Temporal Microwave Emission from a Maser Using Electrons Orbiting a Positively-Charged Wire*

Igor Alexeff, Fred Dyer
Hamid F. Karimy and Wlodek Nakonieczny
University of Tennessee; Knoxville, Tenn. 37996-2100

We have developed a maser in which electrons orbiting a positively charged wire couple to the radio frequency field of a cavity resonator and emit microwaves[1]. The electrons have been generated by a gas discharge. The object is to produce microwaves down to a wavelength of 0.1 millimeter. We have successfully produced 10-watt pulses down to a wavelength of 4 millimeters, with lack of present diagnostics blocking further progress.

One disadvantage of the past experiments is that the microwaves have been produced in pulses lasting for only about 20 microseconds, while for communications purposes, one would like continuous-wave emission.

Recently, we have tried improving our apparatus to try to determine if pulsed operation is a basic property of our maser. We have done this by improving the interior structure of the tube to prevent spurious, short-circuiting discharges, by adding a hot filament cathode, and by limiting the current from the capacitor pulsed power supply with a series resistor (Figure 1). So far, we have successfully stretched the pulse emitted at 3cm from 20 microseconds to 5 milliseconds. The results are not completely satisfactory, as the tube occasionally reverts to 20 microsecond emission spontaneously, for unknown reasons. However, we have succeeded in our objective of demonstrating that 20 microsecond emission is not a necessary consequence of our maser's operation.

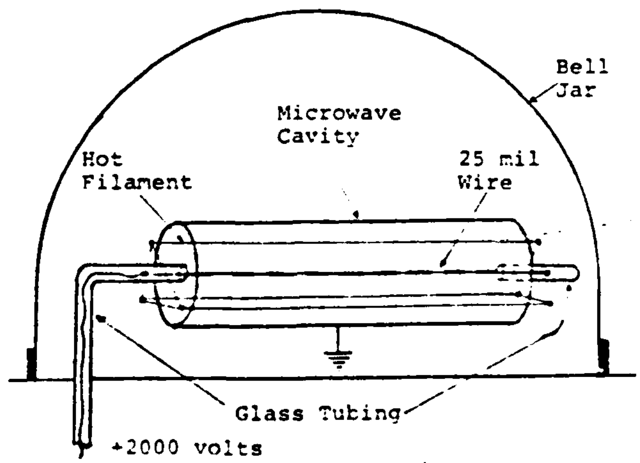

Figure 1. Maser with improved interior structure.

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*Supported by the Air Force Office of Scientific Research under contract AF AFOSR-82'-0045 Alexeff

[1]Igor Alexeff and Fred Dyer, Physical Review Letters 45, 351 (1980).

Please refer to "First and Final Call for Papers" announcement for instructi[ons] in preparing your abstract

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High Power Microwave and Sub-millimetre Wave Generation

Subject category number:
18

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( ) Special requests for placement of this abst[ract]

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I am a member of the Comm[ittee] on Plasma Science and Application

(X) yes ( ) no

This form, or a reasonable facsimile, plus two Xerox copies must be received NOT LAT[ER] THAN FEBRUARY 1ST, 1982 at the following address: A.J. Alcock, Chairman, 1982 International Conference on Plasma Science, c/o National Research Council of Canada, Ottawa, Ontario, Canada K1A OR6.

e. Personnel

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   Experimental Work

3. Wlodek Nakonieczny
   Ph.D. Student (Physics)
   Computer Simulation

4. Hamid F. Karimy
   B.E.E. Student
   Experimental Work

f. Interactions

Meetings for Report

APS Plasma Physics Division

New Orleans, LA
November 1-5, 1982

I.E.E.E. International Conference on Plasma Science

Ottawa, Canda
May 17-19, 1982

APS Plasma Physics Division

New York, NY
October 12-16, 1981

1982 Microwave Power Tube Conference Meeting in Naval Postgraduate School

Monterey, CA
Mon. April 26-Wed April 28, 1982

Meeting at Hughes

Malibu, CA
Friday January 29, 1982